INVESTIGATION OF THERMIONIC EMISSION AT LOW INTENSITY WITH A GEIGER COUNTER

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ABSTRACT. An attempt has been made to investigate thermionic emission at low intensities by counting the individual electrons with a Geiger counter. In the first case, a Geiger counter with its axial anode wire is heated to serve as an electron emitter. Subsequently, a heated offset wire parallel to the axial wire anode is operated as an electron emitter. In either case, Richardson's thermionic emission equation is verified while the lowest figure of the thermionic current density measured is 3 electrons/cm^2. sec.

INTRODUCTION

All the methods of investigating thermionic emission reported before have been based on measurements of integral emission current. The lowest limit of thermionic current density measured is that due to Germer (1925). Working between the temperature range of 1440°K and 2475°K, he measured a variation of current from 10^{-15}amp. to 10^{-4}amp. A current of 10^{-15}amp. is equivalent to an emission of approximately 6×10^{3} electrons/cm^2.sec. Furthermore, with most substances the current cannot be measured on a sensitive galvanometer at temperatures below 1000°C. In order to explore thermionic emission phenomena in the region of comparatively low temperatures it is imperative that individual electrons should be counted. The simplest equipment for such an exigency is the Geiger counter. Since the Geiger counter is a gas filled device the effect of gaseous atmosphere on thermionic emission from a filament, of say tungsten, becomes important. Langmuir (1913, 1914) investigated the effect of different gases on the emission of tungsten at about 2000°C. The gases experimented with, included hydrogen, water vapour, oxygen, nitrogen and argon. His investigations revealed that the presence of argon did not alter appreciably the values of the Richardson constants of the emitter. The only effect of argon when present in a small quantity is to facilitate the attainment of saturation through the action of positive ions, formed by impact ionization, in reducing the effect of mutual repulsion of electrons. No doubt when the pressure of the argon is appreciable the current will be magnified owing to the ionization by collisions, but the effect would be of importance in the detection of individual electrons. It is natural, therefore, to expect that the behaviour of other inert gases would be analogous to that of argon. Consequently, there is a reasonable prospect of studying thermionic emission with the help of a non-selfquenching Geiger counter filled sith an inert gas at an appropriate pressure. The self-quenching counters, however, with a mixture of argon and organic vapour, would change the values of the thermionic emission constants. Such an effect has indeed been observed by Ettinger and Móscicki (1962). Nevertheless, either types of counters may be used for the study of low temperature emission of electrons.

This paper describes the detection of thermal electrons from a hot tungsten wire anode in a Geiger counter. A further modification in which a heated offset wire parallel to the axial wire anode served as an electron emitter is also reported. In both these cases Richardson's thermioniq emission equation is verified. An attempt was also made to operate a Geiger counter with reversed potentials, viz., by using the axial wire as a cathode. An account of this investigation will form the subject matter of a subsequent communication.

THERMIONIC EMISSION FROM A HOT TUNGSTEN WIRE ANODE

It is well known that a Geiger counter can detect an ionizing event if it can release a single electron anywhere within the sensitive volume of the counter. Thus, a Geiger counter should be able to detect thermal electrons if they are produced within the sensitive volume of the counter.

In a thermionic vacuum tube of cylindrical geometry, the heating current of the axial wire generates a magnetic field of heating current which may, as Richardson (1914) suggested, play an important role, sometimes effectively preventing electrons from reaching the anode, even with a high potential. Hull (1926) found that electrons are deflected in the direction of the electron current in the wire and describe elongated cycloidal paths. However, the effect is small with filaments of ordinary size, and is masked by the relatively enormous effect of the accelerating radial voltage gradient.

With applied potentials reversed the radial voltage gradient exerts a retarding force on the electrons, preventing them from reaching the cylindrical anode. Thus, a Geiger counter, with a heated axial filament, may be likened to a unidirectional gas filled device. Nevertheless, it does respond to the emission of individual electrons from the heated filament. This is so, because the cyloidal return path traversed by the emitted electron in the vicinity of the wire produces a Townsend avalanche culminating in a Geiger pulse.

EXPERIMENTAL CONSIDERATIONS AND RESULTS

The experimental arrangement adopted for the study of thermionic emission with a Geiger counter, the hot tungsten anode wire serving as the thermal electron emitter is shown in block diagram in fig. 1. It consisted of a Geiger counter, an insulated battery to heat electrically the axial anode wire, Maier-Leibnitz's quenching circuit and a scaler. The Geiger counter consisted of a copper cathode having a diameter 1.5 cms. and length 6 cms. A fine wire of tungsten having a diameter of 4 mil served as the axial anode which was heated to produce thermal electrons. The sensitive volume of the counter was restricted to the central portion of the axial anode wire with the help of glass sleeves at the ends. The

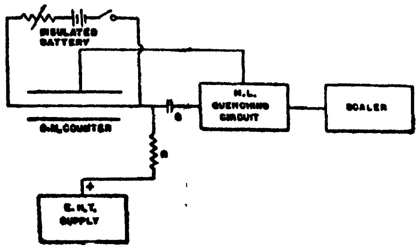

Fig. 1. Block diagram of the experimental arrangement adopted for the study of thermionic emission from a hot tungsten wire anode.

counter voltage was supplied from an electronically stabilised H.T. supply unit. Fig. 2 shows details of Maier-Leibnitz's quenching circuit which was used for quenching the Geiger counter. This circuit works on the multivibrator principles but uses two different grids of input tube for the signal and the regenerative feed back. The discharge pulse of the counter excites the quenching circuit to one

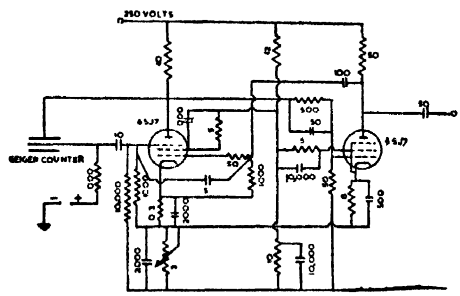

Fig. 2. Maier-Leibnitz's quenching circuit.
Resistances are given in kilo ohms, capacitances in micromicrofarads.

oscillation during which the counting voltage is kept below the threshold and the counter has time to recover. At the end of the oscillation (after about 0.2 millisecond) the counter voltage and all other voltages of the circuit are restored rapidly to their initial values. Thus, the next count can take place under exactly the same conditions as the first. The output pulses of the quenching unit are all equal and no discharge occurs in the Geiger counter while the quenching circuit is unable to quench them. The output pulses from the M.L. quenching unit, were fed to a scaler for registration of the pulses. The temperature of the heated anode wire was determined by the resistance measurement of the anode wire with the help of a potentiometer which was calibrated against a standard cell (Weston type D-550-B).

As the temperature of the axial wire was gradually increased there was a progressive increase in pulse size till the counter stepped into the region of stabilized corona.

To arrive at a reasonable understanding of what happens within the volume of the Geiger counter when the thin axial wire is being heated it may be assumed that the radiation and convection effects are negligible and the radial temperature distribution may be determined by the steady state conduction process alone. In the steady state we have $\nabla T = 0$ and for a radial distribution of temperature

$$\frac{1}{r} \frac{d}{dr}\left(r \frac{dT}{dr} \right) = 0 \qquad \dots \quad (1)$$

solving for T, we get

$$T = C \log_e r + B \qquad \dots \quad (2)$$

where C and B are constants.

Assuming that the cylinder remains, more or less, at the room temperature, so that $T = T_0$ at $r = b$ (the radius of the cylinder) and $T = T_1$, at $r = a$ (the radius of the axial wire), the temperature at any point r, from the axis of the cylinder is, therefore, given by

$$T(r) = \alpha \log_e r + \beta \qquad \dots \quad (3)$$

where, α and β are determinable constants.

There is also slight increase in pressure of the gas within the counter volume. The pressure is independent of r. But the gas density $n(r)$ is given by

$$n(r) = P/T(r) \qquad \dots \quad (4)$$

Around the axial wire in the Townsend avalanche region which is of the order of 5 wire radii there is a considerable attenuation of the gas density. This lowers the threshold potential of the counter which manifests itself as an increase in overvoltage of the counter for the existing potential distribution.

An explanation for the enhancement of the overvoltage due to the attenuation of the density of the gaseous mixture in the neighbourhood of wire may be sought in the fact that Paschen's law governs at least roughly all spark-breakdown phenomena. Thus V_c, the starting potential of corona or glow may be taken as governed by Paschen's law which may be given by the function equation

$$f\left(\frac{V_c}{P\delta} \right) = \frac{1}{P\delta} \log \frac{1}{\phi(V_c/P\delta)} \qquad \dots \quad (5)$$

It may be seen that on the basis of the above equation V_c the starting potential is a function of P

$$\text{i.e.} \quad V_c = F(P\delta) \qquad \dots \quad (6)$$

This has been found experimentally to be true. It was indeed discovered experimentally by Paschen (1889), and was proved theoretically by Townsend (1915), Schumann (1923) and Thomson (1933) on general considerations irrespective of the mechansim assumed. It is obvious that it holds for uniform or non-uniform fields caused by gap geometry.

The physical interpretation of this law is relatively simple. The product $P\delta$ represents in essence the number of molecules to be encountered by an ion or an electron crossing the gap. This number, as with all applications of Avagadro's law depends primarily on gas density and not on pressure alone. Hence one can really insert $\rho\delta$ for $P\delta$ in the Paschen's law equation, where ρ is the gas density. Hence, where temperature is varied in the vicinity of the wire by electrically heating the same the value of V_c becomes a function of $\rho\delta$. Since the electric field remains, more or less constant, the attenuation of ρ in the vicinity of the axial wire, lowers the value of V_c, which is the starting potential for stabilized corona. In other words, the entire Geiger region is shifted towards the lower voltage side and the threshold potential for Geiger action is correspondingly lowered. Such a situation implies that the Geiger counter is being operated at higher overvoltage than previously. Thus the operation of lowering the density of the enclosed gas in the vicinity of the wire is really equivalent to the enhancement of the operating voltage under normal conditions

It is, therefore, required that the potential across the counter had sometimes to be lowered to confine its range of operation within the Geiger region as the temperature of axial anode wire was gradually raised to produce an adequate

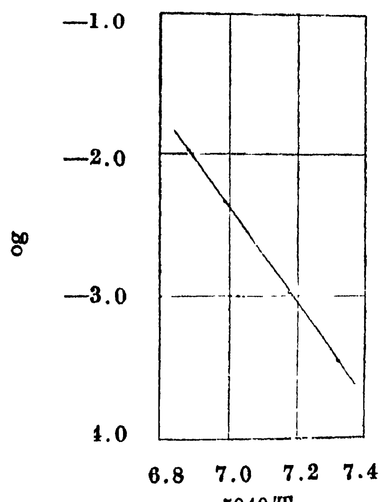

Fig. 3. Richardson's plot for the hot tungsten wire anode in a self quenching Geiger counter.

number of thermal electrons. It was further noted that the plateau of Geiger counter was consistently shortened as a result of the attenuation of the density of the enclosed gas in the vicinity of the wire. A probable deterioration of the plateau on account of an axial thermal gradient was indeed pointed out by McCutchen (1956) on theoretical considerations. The preliminary experiments on thermionic emission were performed simultaneously with a self-quenching counter and with a pure gas (argon) filled counter. The results obtained are shown in tables 1 and 2.

TABLE 1

Thermionic emission from a Tungsten wire with a self-quenching counter

T (in °K)	N (Number of counts per minute)	$5040/T$	N/T^2	ϕ (in eV)	A (amp./cm². degree²)	Remarks
688	166	7.324	3.506×10^{-4}			
702	533	7.180	1.081×10^{-3}	3.39	50.2	Area of the emitting surface not well defined.
721	2454	6.990	4.722×10^{-3}			
732	5795	6.885	1.081×10^{-2}			

Note : (1) $5040/T = 1$ eV/kT $\log_e{}^{10}$ where k is the Boltzmann constant.

(2) The results have been confined to low temperature measurements of thermionic emission because of deadtime difficulties encountered at higher temperatures.

TABLE 2

Thermionic emission from a tungsten wire with a non-selfquenching counter

T (in °K)	N (Number of counts per minute)	$5040/T$	N/T^2	ϕ (in eV)	A (amp./cm². degree²)	Remarks
915	101	5.508	1.179×10^{-4}			
931	286	5.414	3.301×10^{-4}	4.62	71.8	Area of the emitting surface not well defined.
953	1142	5.287	1.257×10^{-3}			
965	2336	5.223	2.509×10^{-3}			

Note : (1) $5040/T = 1\ eV/kT\ \log_e{}^{10}$ where k is the Boltzmann constant.

(2) The results have been confined to low temperature measurements of thermionic emission because of deadtime difficulties encountered at higher temperatures.

A plot of $\log_{10} N/T^2$ versus $5040/T$, where N/T^2 is the number of counts per minute per degree squared and T the corresponding temperature of the axial anode wire in degrees absolute yielded a straight line satisfying the Richardson's thermionic emission equation. The work function for tungsten as calculated from the slope of the plots (figs 3 and 4) was 3.39 eV in a selfquenching counter and 4.62 eV in an argon filled counter.

Looking at the results it seems likely that in the first case the unexpected lowering of the normal work function in a retarding field may be due to the presence of adsorbed layers of the selfquenching vapour on the surface of the axial anode wire. However, in the case of pure argon filled non-selfquenching counter, the work function of tungsten anode is higher. The higher value may be consistent with Schottky's mirror image theory.

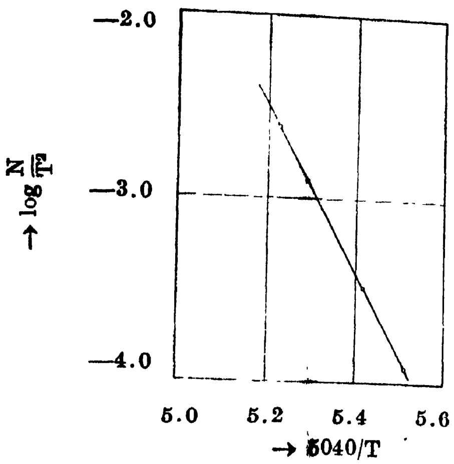

Fig. 4. Richardson's plot for the hot tungsten wire anode in a non-selfquenching Geiger counter.

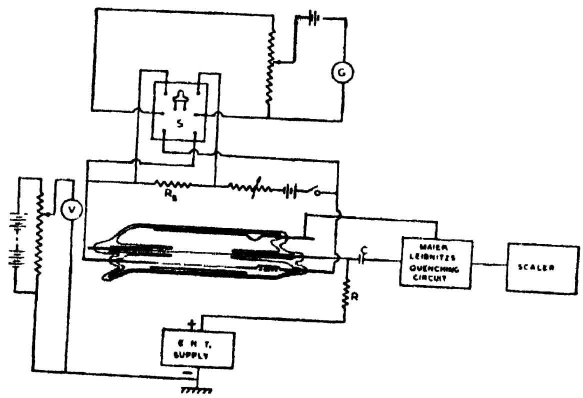

Fig. 5. Schematic diagram of the experimental arrangement for the study of thermionic emission (using an offset wire as thermal electron emitter).

THERMIONIC EMISSION FROM A HEATED OFFSET WIRE IN A GEIGER COUNTER

An analysis of the experimental results presented above indicates that a normal Geiger counter, with a heated anode wire is not well suited for a study of thermionic emission for the following reasons.

(1) the emitted electrons cannot escape against a retarding field; they return back to the heated anode.

(2) the radial thermal gradient surrounding the axial anode attenuates the density of the filling gas in its vicinity resulting in the enhancement of the neighbouring field gradient and proneness to continuous discharge.

In order to circumvent these difficulties a new counter was fabricated with an extra offset wire parallel to the axial wire anode. The offset wire was electrically heated to serve as electron emitter. It was usually maintained at a potential, appropriate for its location within the existing field distribution, by means of an auxiliary battery. However, it did not make much difference in measurement when the offset wire was kept floating while being heated by an independent battery.

EXPERIMENTAL ARRANGEMENT AND RESULTS

Fig. 5 depicts schematically the experimental arrangement adopted for the study of thermionic emission using an offset wire in a Geiger counter as the thermal electron emitter. The offset wire was heated electrically by an insulated storage battery. The other components of the circuit consisted of a standard resistor (1ohm), a potentiometer, an adjustable voltage source, an E.H.T. supply for the Geiger counter, Maier-Leibnitz's quenching circuit and a scaler. The modified Geiger counter consisted of a pyrex glass tube envelope of diameter 3.8 cms. whose inner surface was coated with aquadag to form the cylindrical cathode of length 8 cms. The axial tungsten wire had a diameter of 0.1 mm. spotwelded on either side to thick tungsten leads, which in turn were sealed into protecting glass tubes and were available for electrical connections. The offset wire for producing thermal electrons had a diameter of 0.15 mm. and was stretched parallel to the axial anode wire. One end of the offset wire was spotwelded to a tungsten rod while the other end was spotwelded to another tungsten rod via a small tungsten spring to keep the offset wire taut while being heated.

The necessity of keeping the diameter of the offset wire somewhat thicker than the axial wire was dictated by circumstances which led to the simultaneous appearance of an image inverted pulse superimposed on a normal Geiger pulse at the axial wire terminal, as reported earlier by the authors (Sastri *et al*, 1967).

The counting portion of the counter for thermal electrons was confined to a length of 4.5 cms. by providing suitable glass tubes at the end of the axial anode wire. Both the offset wire and the axial anode wire were flashed in high vacuum while the counter was being evacuated, in order to smoothen the asperities on the surface. The counter was filled at 11cms. Hg pressure with 10 cms. argon stated to be "spectroscopically pure" and 1 cm. of hydrogen. The gaseous mixture was introduced into the counter after passing through traps immersed in liquid nitrogen. Maier-Libnitz's quenching circuit (fig. 2) was used for quenching the Geiger counter. The output pulses from the M.L. quenching unit were fed to a scaler for registration of pulses. From an auxiliary voltage source, polarisation potential adjusted to the free wire potential in the electrostatic field of the counter, was applied to the offset wire with the help of a voltmeter. The temperature of the offset wire was determined by the resistance measurement as mentioned above.

Measurements were taken in the temperature range of 841°K to 934°K. The results obtained are presented in the table 3. It may be seen from this table that the counts due to thermal electrons varied from 40 per minute at 841°K to 18,880 per minute at 934°K. The former count gives the lowest figure of the thermionic current density measured as equivalent to 3 electrons/cm^2.sec. at a temperature of 841°K.

Fig. 6 shows the Richardson's plot $\log_{10}N/T^2$ versus $5040/T$, where N/T^2 is the number of counts per minute per degree squared and T the corresponding

TABLE 3

Thermionic emission from a heated offset wire in Geiger counter

Temp. (in °K)	N (Number of counts per minute)	$5040/T$	N/T^2	ϕ (in eV)	A (amp./cm^2. degree^2)	Remarks
841	40	5.992	5.656×10^{-5}			
852	88	5.916	1.213×10^{-4}			
864	210	5.833	2.813×10^{-4}			
882	700	5.714	8.997×10^{-4}	4.33	62.2	Area of the emitting surface not well defined.
904	2945	5.575	3.602×10^{-3}			
921	8670	5.471	1.022×10^{-2}			
934	18880	5.396	2.165×10^{-2}			

temperature of the offset wire in degree absolute. The work function for tungsten as calculated from the slope of the plot is 4.33 eV, which compares not unfavourably

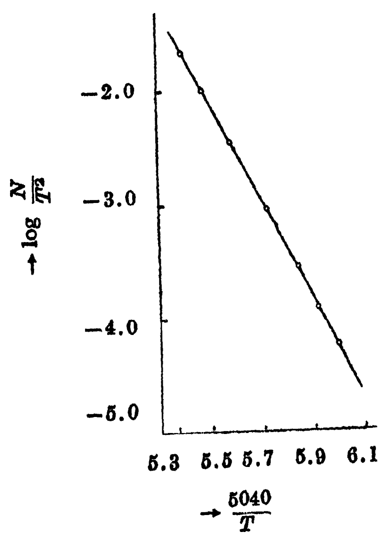

Fig. 6. Richardson's plot for the emission of electrons from a heated offset wire of tungsten.

with the accepted value of 4.54 eV. The slight diminution of work function may perhaps be attributed to the presence of hydrogen in the gaseous mixture.

For instance, Weissler and Wilson (1953) have reported a diminution in work function of the order of 0.5 eV in hydrogen or nitrogen atmosphere whereas the inert gases produced no change at all employing Oatley's contact potential method of measurement.

Although the present investigation is more or less of a qualitative and introductory character, it is expected that further refinement in measurement and technique, employing an anti-coincidence method for the elimination of the cosmic ray background, would improve the accuracy of measurement at lower temperature by at least one order of magnitude.

Further investigations have been carried out on the energy distribution of thermionically emitted electrons with the modified form of the countor operating in the proportional region. The results will be reported in a future communication.

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